1. WORK

Work is used to describe any activity which involves physical or mental labour.

Work is said to be done when a force displaces a body through certain distance in the direction of force.

For example

(i) A boy pulling a toy car with a string. The change in position of the toy car shows that some work has been done.

(ii) A bullock pulling a cart. The cart moves. The bullock pulls the cart with a force which moves the cart in the direction of force and hence the work is said to be done.

The work done by a force on a body depends on two factors :

(i) Magnitude of the force.

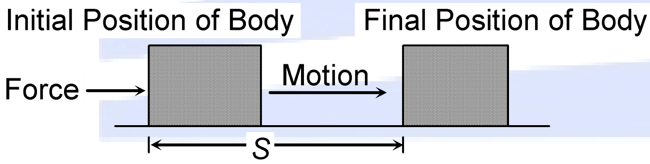
(ii) Distance through which the body moves in the direction of force.

1.1 MEASUREMENT OF WORK

Let a constant force, F acts on an object and displaces the object through a distance 's' in the direction of the force applied. Then, the work done W is given by the product of force exerted on the body and the distance moved by the body in the direction of force. i.e.

Work = Force × Displacement

$W = F \times s$



Work done has only magnitude and no direction. Therefore, it is a scalar quantity.

If F = 1 N and s = 1 m, then work done by the force will be 1 Nm.

The S. I. unit of work is Joule or Nm.

1 Joule is the amount of work done on an object when a force of 1 N displaces it by 1 m along the line of action of force.

The condition for a force to do work is that it should produce motion in an object.

If however the distance moved is zero, then the work done on the object is always zero.

For example :

(i) A man pushing a stationary wall. There is no movement of the wall. So the work done by the man on the wall is zero.

However the work done on the body of the man himself is not zero. This is because when the man pushes the wall, his muscles are stretched and blood is displaced to the strained muscles more rapidly. So, due to energy consumption man feels tired.

(ii) A man standing still at a bus stop with heavy suitcases in his hands may get tired soon but there is no work done in this situation.

This is because the suitcases held by the man do not move at all.

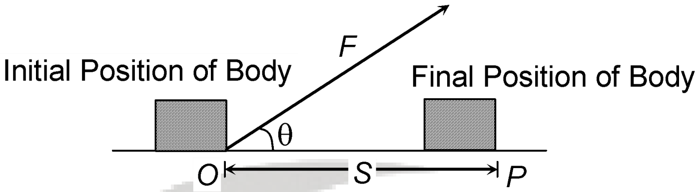
1.2 POSITIVE WORK DONE AND NEGATIVE WORK DONE

Consider a situation in which the force and the displacement are in the same direction : a baby pulling a toy car parallel to the ground.

The baby has exerted a force is the direction of displacement of the car. In this situation, the work done will be equal to the product of the force and displacement. In such situations, the work done by the force is taken as positive.

Now consider another situation in which an object is being displaced by the action of forces and we identify one of the forces, F acting opposite to the direction of the displacement S, i.e., the angle between the two directions is 180°, in such a situation, the work done by the force is taken as and denoted by the minus sign. The work done by the force is $F \times (-s)$ or $(-F \times s)$.

Work done is zero when a force acts at right angles to the direction of motion of the body.



(a) **When the force acts at right angles to the direction of motion.**

When force acts at right angles to the direction of motion of a body then the angle θ between the direction of motion and direction of force is 90°.

Now, cos 90° = 0, so the component of force, $F \cos 90°$ becomes zero and hence work done = 0

$W = F \cos 90° \times s$

$W = F \times 0 \times s$

$W = 0$

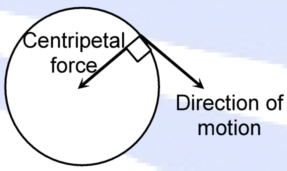
(b) **Work done on a body moving in a circular path**

To keep a body moving in a circle, there is a force acting on it directed towards the centre. This force is called as centripetal force.

The work done on a body moving in a circular path is also zero.

This is because when a body moves in a circular path then the centripetal force acts along the radius of the circle and it is at right. angle to the motion of the body.

Thus, the work done in the case of earth moving round the sun is zero and the work done in the case of a satellite moving round the earth is also zero.



2. ENERGY

The energy of a body is its capacity of doing work.

Let us understand the concept of energy with some examples.

(i) When a fast moving cricket ball hits a stationary wicket, the wicket is thrown away.

(ii) An object when raised to a certain height gets the capability to do work.

(iii) When a raised hammer falls on a nail placed on a piece of wood, it drives the nail into the wood.

From all these examples we conclude that an object that possesses energy can exert a force on another object. When this happens energy is transferred from the former to the latter.

The second object may move as it receives energy and therefore do same work. Thus, the first object had a capacity to do work. This implies that any object that possesses energy can do work.

The energy possessed by an object is thus measured in terms of its capacity of doing work.

The unit of energy is, therefore, the same as that of work, that is, Joule (J).

1 Joule is the energy required to do 1 Joule of work.
Sometimes, a larger unit of energy called Kilo Joule (KJ) is used.
1 KJ = 1000 J.
The unit of energy called 'Joule' is named after a physicist. ***'James Prescott Joule'.***

2.1 FORMS OF ENERGY

There are various forms of energy. Such as :
(i) Kinetic Energy
(ii) Potential Energy
(iii) Chemical Energy
(iv) Heat Energy
(v) Light Energy
(vi) Sound Energy
(vii) Electrical Energy
(viii) Nuclear Energy

The kinetic energy and potential energy taken together is known as mechanical energy.

2.1.1 Kinetic Energy

The energy possessed by a moving body by virtue of its motion is called kinetic energy. It is given by

kinetic energy = $\frac{1}{2}mv^2$

Examples :
(i) A speeding car
(ii) A rolling stone
(iii) A running athlete
(iv) A flying air craft

Derivation of Kinetic Energy :

Let us now express the kinetic energy of an object in the form of an equation. Consider an object of mass, '*m*' moving with a uniform velocity *u*.

Let it now be displaced through a distance *s* when a constant force, *F* acts on it, in the direction of its displacement.

Now work done = $F \times s$ … (i)

The work done on the object will cause a change in its velocity. Let its velocity change from *u* to *v*.

Let, *a* be the acceleration produced.

The relation connecting the initial velocity (*u*) and final velocity (*v*) of an object moving with a uniform acceleration *a*, and the displacement *s* is

$$v^2 - u^2 = 2\ as$$

This gives,

$$S = \frac{v^2 - u^2}{2a} \quad \ldots(ii)$$

We know, $F = m \times a$ …(iii)

So, putting the values of '*s*' and 'F' in equation (i)

$$W = m \times a \times \left(\frac{v^2 - u^2}{2a}\right)$$

or $$W = \frac{1}{2}m\,(v^2 - u^2)$$

If the object is starting from its stationary position, that is u = 0, then.

$$W = \frac{1}{2}mv^2$$

It is clear that the work done is equal to the change is the kinetic energy of an object.

If $u = O,$ the work done will be $\frac{1}{2}mv^2$

Thus, kinetic energy possessed by an object of mass, m and moving with a uniform velocity, v is

$$E_K = \frac{1}{2}mv^2$$

From this formula, it is clear that

(i) The kinetic energy of a body is directly proportional to the mass of the body.

(ii) The kinetic energy of a body is directly proportional to the square of velocity of the body.

Since the kinetic energy of a body depends on its mass and velocity, therefore heavy bodies moving with high velocities have more kinetic energy, than slow moving bodies of small mass.

2.2 POTENTIAL ENERGY

It is the energy possessed by the body due to its position or configuration. Configuration means the change in relative position of its parts or condition.

(i) Potential energy due to position : A body lying in an elevated position such as a stone lying on the roof of a building or water stored in a reservoir has got some potential energy. When allowed to fall, it is capable of doing some work. If it were raised higher, it could do more work and hence would have possessed more potential energy.

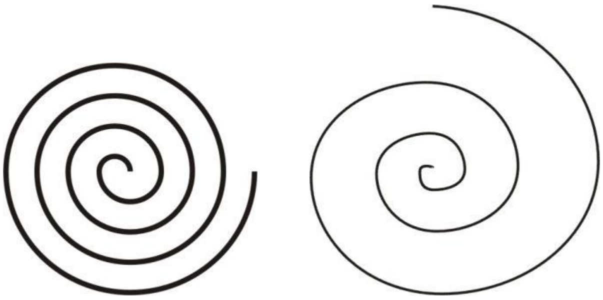
These are the examples of potential energy possessed by a body due to its position. This type of potential energy is also called gravitational potential energy.

(ii) Potential energy due to configuration or elastic potential energy or strain potential energy : Elastic potential energy is due to a change in the shape of the body.

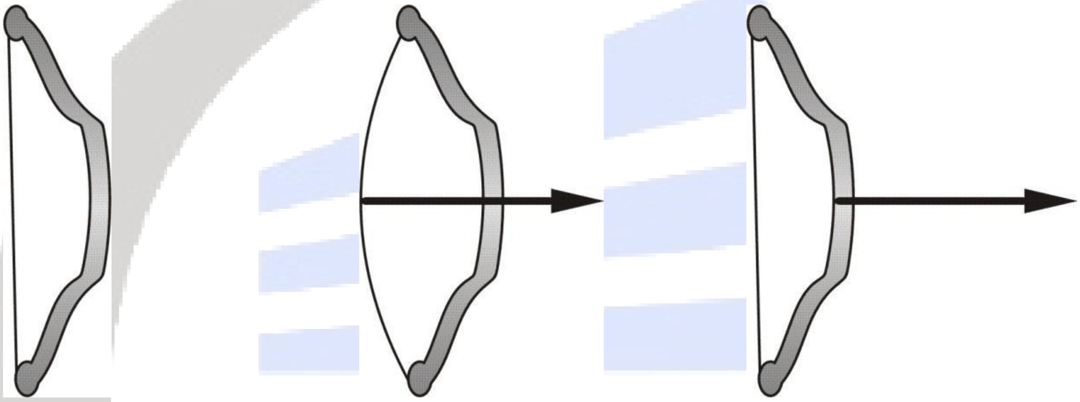
The change in shape of a body can be brought about by compressing, stretching, bending or twisting.

Some work has to be done to change the shape of a body (temporarily). This work gets stored is the deformed body in the form of elastic potential energy. When this deformed body is released it comes back to its original shape and size and the potential energy is given out in some other form. For example a wound up circular spring possesses elastic potential energy which drives a wind up toy.

When we wind up the spring of a toy car using a winding key, then some work is done by us due to which the spring gets coiled more tightly. The work done in winding the spring gets stored up in the tightly coiled up spring in the form of elastic potential energy. When the wound up spring is slowly released, its potential energy is gradually converted into kinetic energy which turns the wheels of the toy car and makes it run.



(b) A stretched bow possesses potential energy due to the relative position of different parts. When bow is pulled from position A to position B the energy spent in pulling the bow is converted into strain potential energy of the bow. This energy given is converted into kinetic energy when it is released (position C).



(A) (B) (C)

Potential energy of an object at a height

An object increases its energy when raised through a height. This is because work is done on it against gravity while it is being raised. The energy present in such an object is the gravitational potential energy.

The gravitational potential energy of an object at a point above the ground is defined as the work done in raising it from the ground to that point against gravity.

To arrive at an expression for the gravitational potential energy of an object at a height, consider a object of mass, m. Let it be raised through a height, h from the ground. A force is required to do this. The minimum force required to raise the object is equal to the weight of the object, mg.

The object gains energy equal to the work done on it. Let the work done on the object against gravity be. That is,

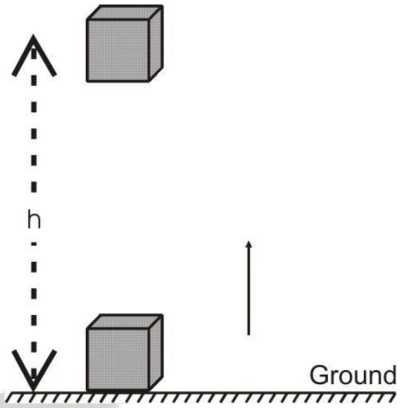
Work done, W = force x displacement

$= mg \times h$

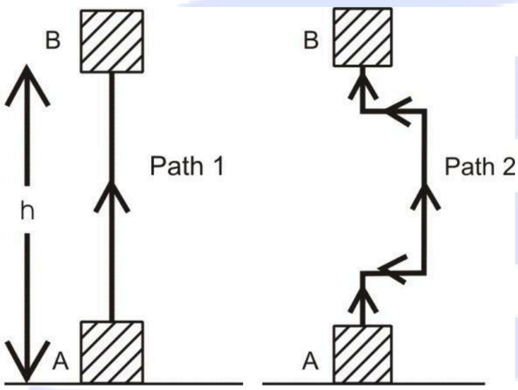
$= m\, g\, h$

Since work done on the object is equal to *mgh,*an energy equal to *mgh* units is gained by the object. This is the potential energy (E_p) of the object.

$E_p = mgh$



It is useful to note that the work done by gravity depends on the difference in vertical heights of the initial and final position of the object and not on the path along which the object moved. Figure below shows a case where a block is raised from position A to B by taking two difference paths. Let the height, AB = h. In both the situations the work done on the object is mgh.



The potential energy of an object at a height depends on the ground level or the zero level you choose. An object in a given position can have a certain potential energy with respect to one level and a different value of potential energy with respect to another level.

3. LAW OF CONSERVATION OF ENERGY

Energy can be transformed from one form to another.

According to law of conservation of energy whenever energy gets transformed, the total energy remains unchanged, i.e. Energy can neither be created nor destroyed. The total energy before and after the transformation remains the same.

The law of conservation of energy is valid in all situations and for all kinds of transformations.

Consider an example.

Let an object of mass, '*m*' be made to fall freely from a height '*h*'. At the start the potential energy is $m \times g \times h$ and kinetic energy is zero.

Kinetic energy is zero because its velocity is zero.

The total energy of the object is thus *mgh*. As it falls, its potential energy will change into kinetic energy. If *v* is the velocity of the object at a given instant the kinetic energy would be $\frac{1}{2}mv^2$.

As the fall of the object continues, the potential energy would decrease while the kinetic energy would increase. When the object is about to reach the ground, $h = 0$ and '*v*' will be the highest.

Therefore, the kinetic energy would be the largest and potential energy the least. However the sum of the potential energy and the kinetic energy of the object would be the same at all points.
That is
Potential energy + kinetic energy = constant
Or

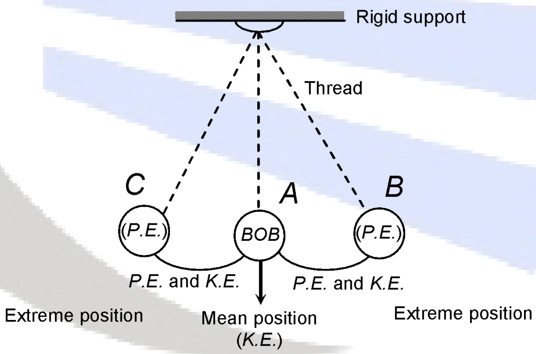
$$m g h + \frac{1}{2}mv^2 = \text{constant}$$

During the free fall of the object the decrease in potential energy at any point in its path, appears as an equal amount of increase in kinetic energy. There is thus, a continual transformation of gravitational potential energy into kinetic energy.

3.1 CONSERVATION OF ENERGY IN A SIMPLE PENDULUM

A swinging simple pendulum is an example of conservation of energy.

(i) A simple pendulum consists of a small metal ball or bob suspended by a long thread from a rigid support, such that the bob is free to swing back and forth when displaced.
(ii) Initially, the simple pendulum is at rest with its bob in the centre position or mean position.
(iii) When the pendulum bob is pulled to one, side to position *B* and then released the bob starts swinging between positions *B* and *C*.
(iv) When the pendulum bob is at position *B*, it has only potential energy and no kinetic energy
(v) As the bob moves down from position *B* to position *A*, its potential energy goes on decreasing but its kinetic energy goes on increasing.
(vi) When the bob reaches the centre position *A*, it has only kinetic Energy but no potential energy.
(vii) As the bob goes from position A towards position *C*, its kinetic energy goes on decreasing but its potential energy goes on increasing.
(viii) On reaching the extreme position *C*, the bob stops for a very small instant of time. So at position *C* the bob has only potential energy but no kinetic energy.



Conclusion : At the extreme positions *B* and *C*, all the energy of pendulum bob is potential and at the centre position *A*, all the energy of the bob is Kinetic.
At all the other intermediate positions, the energy of pendulum bob is partly potential and partly kinetic.
But the total energy of the swinging pendulum at any instant of time remains the same or conserved.

4. ENERGY CONVERSIONS OR ENERGY TRANSFORMATION

(i) An **Electric motor** used in electric fans, washing machines, refrigerators, mixer and grinder etc. convert

Electrical energy → Mechanical energy.

(ii) A **Generator** converts
Mechanical energy → Electrical energy.

(iii) An **Electric Iron** converts
Electrical energy → Heat Energy

(iv) An **Electric** Heater converts
Electrical Energy → Heat Energy

(v) An **Electric** Bulb converts
Electrical Energy → Light Energy

In an electric bulb flow of electricity causes the tungsten filament in the bulb to become white hot and give out light. So in an electric bulb the energy transformation takes place as follows :

Electrical Energy → Heat Energy → Light Energy

(i) **Solar Cell :** Light Energy → Electrical Energy

(ii) **Solar Heater :** Light Energy → Heat Energy

(iii) **Burning LPG :** Chemical Energy → Heat Energy + Light Energy

(iv) **Cell or Battery :** Chemical Energy → Electrical Energy

(v) **Car Engine :** It converts the Chemical energy of petrol into heat energy and then into kinetic energy or mechanical energy.
Chemical → Heat → Kinetic Energy or Mechanical Energy

(vi) **Steam Engine :** Heat Energy → Kinetic Energy

(vii) **Radio :** Electrical Energy → Kinetic Energy of diaphragm in a speaker → Sound Energy

(viii) **At Hydro electric power station**, the potential energy of water is transformed into kinetic energy and then into electrical energy.

(ix) **At thermal power station** : Chemical energy → Heat Energy → Kinetic Energy → Electrical Energy.
When coal is burnt, the chemical energy of coal is changed into heat energy. This heat energy converts water into steam. The high pressure steam turns the steam turbines changing the heat energy into kinetic energy. The turbines run electricity generators which convert kinetic energy into electrical energy.
Chemical Energy _→ Heat Energy _→ kinetic energy _→ Electrical energy

5. COMMERCIAL UNIT OF ENERGY

The commercial unit of energy is kWh (Kilowatt hour).

The unit 'joule' is too small and hence is inconvenient to express large quantities of energy so we use kWh as unit of energy for commercial purposes.

1 kWh is the amount of electrical energy consumed when an electrical appliance having a power rating of 1 kilowatt is used for 1 hour.

The energy used in households, industries and commercial establishments are usually expressed in kilowatt hour. For e.g. electrical energy used during a month is expressed in terms of 'units'. Here 1 'unit' means 1 kWh.

6. POWER

Power is defined as the rate of doing work.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

$$P = \frac{W}{t}$$

Power is the work done per unit time.
For doing work, energy in equal amounts is used so;
Power can also be defined as the rate at which energy is consumed.

$$\text{Power} = \frac{\text{Energy Consumed}}{\text{Time taken}}$$

$$P = \frac{E}{t}$$

Power is a Scalar quantity i.e. having only magnitude but no direction.
S.I. unit of power is watt (W)
1 Watt is the power of an agent, which does work at the rate of 1 J per second.
We can also define 1 W as when the consumption of energy is 1 J/s.

$$1 \text{ watt} = \frac{1 \text{ Joule}}{1 \text{ Second}}$$

For e.g. A bulb of 100 watts power consumes electrical energy at the rate of 100 J/S.
Different electrical appliances have different power ratings.
The greater the power of an appliance and more time it is switched on for, the more electricity it consumes.

The unit of power called watt is named after a Scottish inventer, Engineer and designer James Watt

We express larger rates of energy transfer in KW.

1 Kilowatt = 1000 Watts
1 KW = 1000 W / 100 J/S
1 Megawatt = 1000, 000 watts
1 MW = 10^6 W

Another unit of power is called 'Horse Power' (h.p.)

1 horse power = 746 Watts
1 horse power = 746 W
1 h. p. = 0.75 kW

The unit called 'Horse Power' originated long back when steam engines first replaced 'horses' as a source of power. These days the powers of engines of cars etc. are expressed is the unit called *b.h.p.*

Brake horse power (*b.h.p.*) is the unit of power equal to one horse power which is used in expressing power available at the shaft of an engine.
If the *b.h.p.* of a car is more, it is considered more powerful and it does work more rapidly.